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# Levels in ${}_{80}Hg^{195}$, populated in the decays of $Tl^{195}$ (1.2 h) and $Hg^{195m}$ (40 h)

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With 6 figures in the text

## ABSTRACT

Measurements of the internal conversion electron spectrum of $Tl^{195}$ yielded conversion lines of the following new $\gamma$-transitions in $Hg^{195}$: 225.8 ($M1$), 242.1 ($M1$), 247.3 ($M1+E2$?), 279.2 ($M1$), 562 and 883 keV. The half-life of $Tl^{195}$ was measured to be $1.16 \pm 0.05$ h. A study of the low-energy part of the conversion electron spectrum of $Hg^{195m}$ revealed conversion electron lines of a new 16.20 keV $M1$ transition, converted in mercury. In this spectrum indications were found also of a new 53.3 keV transition of $E2$ character. All sources were electromagnetically mass separated. From the combined information, obtained in the measurements on the two decays, the following level sequence in $Hg^{195}$ is proposed: ground state (1/2 −), 37.16 keV (3/2 −), 53.4 keV (5/2 −), 176.4 keV (13/2 +) and 279.2 keV (3/2 −). The systematics of levels in odd mass mercury isotopes is discussed briefly.

## 1. Introduction

In the present study we continue our work on the decays of odd mass thallium isotopes. Earlier studies have dealt with the decays of $Tl^{199}$ [1] and $Tl^{197}$ [2]. The aim of the work is to collect sufficiently detailed information on the level in odd mass mercury isotopes, to allow a study of their systematics. This task gains interest from the difficulties encountered, when one tries to correlate the levels sequences in $Hg^{201}$ [3] and $Hg^{199}$ [1].

The decay of $Tl^{195}$ has earlier been studied by Knight and Baker [4] and by Andersson *et al.* [5]. Both groups found a half-life of $1.2 \pm 0.1$ h and the latter group reported also on conversion lines of a 37 keV transition.

Since it was found during the present study that the conversion electron spectrum of $Tl^{195}$ indicated a $Hg^{195}$ ground-state spin of 1/2, in contrast to 3/2, proposed [6, 7, 8, 9] from measurements on the decay of $Hg^{195m}$, we also studied the conversion electron spectrum of this nuclide. Evidence was found of an earlier undetected transition, converted in mercury, which explains the disagreement.

## 2. Experimental procedures

The activities were produced in the Werner synchrocyclotron by Hg($p,xn$)Tl and Au($p,xn$)Hg reactions with maximal proton energies of 80 and 45 MeV, respectively. All sources were prepared in the mass separator of this Institute [10, 11], the ion-source oven of which was fed with chemically separated TlCl [12] or with the metallic gold target itself [13]. In the latter case the mercury activities were boiled off the target at a temperature above 1000°C, stable $PbCl_2$ maintaining the discharge in the ion source and also supplying mass-reference lines at the collector. The mass separated ion currents were collected on 2 mg/cm$^2$ aluminium foils. The penetration of the ions into the backing material corresponds to a source thickness of about 3 $\mu$g/cm$^2$, as can be calculated from the formula given by Nielsen [14].

The sources, measuring $1.5 \times 25$ mm, were studied in a double focusing $\beta$-spectrometer [15, 16], adjusted to a momentum resolution of about 0.5 %. The detector window was of 0.9 mg/cm$^2$ Mylar when the $Tl^{195}$ conversion spectrum above 150 keV was studied and of 0.05 mg/cm$^2$ VYNS in the other measurements.

The $Tl^{195}$ spectrum was calibrated against ThB lines in measurements on composite sources of ThB and $Tl^{195}$. The intensities of the lines were obtained by numerical integration of the areas of the peaks and were normalized to the intensities of the $L_I$ 37 and $K$ 242 keV lines, one of which was recorded from every $Tl^{195}$ source. Corrections for absorption in the detector window were applied according to the diagrams of Saxon [17]. The mass assignment of the $Tl^{195}$ lines was based on their half-lives in cases where these could be obtained with sufficient accuracy and on comparisons with conversion electron spectra of mass separated sources of $Tl^{196}+Tl^{196m}$ and $Tl^{194}+Tl^{194m}$, recorded in an earlier investigation [18]. $Tl^{196}+Tl^{196m}$ were found to be the chief contaminants, and in fact most of the recorded lines could be assigned to these nuclides. Whether this was due to the mass separator, not in its best conditions, or to differences between the two masses in the number of conversion electrons per decay is not known, the most plausible explanation being that both factors were cooperating. For experimental details concerning the measurements of the $Tl^{195}$ sources we refer to the earlier papers in this series [1, 2].

The $Hg^{195m}$ spectrum was energy calibrated against conversion electron lines of the 37 keV transition, emitted also in the decay of $Tl^{195}$. The energy value obtained by us (cf. Table 1) was used. The calibration procedure deviated somewhat from the normal one, and will therefore be described in some detail.

It has been shown by Arbman [19] that for the $\beta$-spectrometer used in the present work, there is (in the energy range of interest) a relation $B\varrho/I = a \log I + b$ between the magnetic rigidity $B\varrho$ of a conversion line and the spectrometer current $I$ focusing the line. In calibration runs on ThB samples it has further been found that the parameter $a$ does not change from sample to sample or from run to run, whereas the parameter $b$ is affected by small changes in the source position and is dependent also on the completeness of the demagnetization of the spectrometer prior to the run. These findings were used in our calibration and we thus adjusted the parameter $b$ to give the correct $B\varrho/I$ value for conversion lines of the 37 keV transition and took over the parameter $a$ from earlier calibration runs. It should be remarked that with this procedure the energy differences between conversion lines are often obtained with higher accuracy than their absolute energies.

With $Tl^{195}$ sources the whole energy range 5 to 1000 keV was covered, whereas only limited regions were measured from the $Hg^{195m}$ source.

## 3. Results

### 3.1. *Conversion electron spectrum of* $Tl^{195}$

The interpretation of the conversion lines, which could be assigned to $Tl^{195}$, is given in Table 1. The conversion-shell assignments are based on energy differences and intensity relations between the lines. Conversion in the $K$ shell could be inferred for some of the lines from the empirical thumb-rules $L/M \approx 3$ and $M/N \approx 3$, by which conversion in the $L$, $M$, or $N$ shells can be excluded if corresponding lines of appropriate intensities, converting in the other shells, are absent. The multipolarities of the transitions were obtained from comparisons of the conversion ratios with theoretical values, derived from the calculations by Rose [20] and Sliv and Band [21].

The low $L_{I}/L_{III}$ ratio (34) of the 37 keV transition, as compared with the theoretical ratio (100) for a pure $M1$ transition, is not considered significant, since there are indications that the line interpreted as $L_{III}$ is double. Pure $M1$ multipolarity is therefore proposed, in agreement with the findings in the decay of $Hg^{195m}$ (cf. Table 3). The $K/L$ ratios of the 226, 242 and 279 keV transitions indicate $M1$ multipolarity, but considerable $E2$ admixture is not excluded. The $K/L$ ratio of the 247 keV transition is compatible with a mixture of 30% $M1$ +70% $E2$. This mixture was adopted in the calculations of the total transition intensities, given in Table 1, pure $M1$ multipolarity being assumed for the other transitions.

The half-life of $Tl^{195}$ was measured by following the decay of the $L$ 37 keV complex in the $\beta$-spectrometer. A least squares analysis of the decay curve yielded a value $1.16 \pm 0.05$ h, the error in which is increased ten times above the statistical uncertainty to allow for systematical errors.

*Table 1.* Internal conversion lines in the decay of $Tl^{195}$.

| Adopted transition energy (keV) and multipolarity | Conv. shell | Electron energy (keV) | Half-life (min) | Relative electron intensity | Conversion ratios | Relative total transition intensity |
|---|---|---|---|---|---|---|
| $37.16 \pm 0.11$ | $L_{I}$ | $22.33 \pm 0.11$ | $67 \pm 4$ | 100 | $L_{I}/L_{II} = 9 \pm 2$ | 100 |
| $M1$ | $L_{II}$ | $22.94 \pm 0.12$ | $54 \pm 20$ | $11 \pm 2$ | $L_{I}/L_{III} = 34 \pm 5$ | |
| | $L_{III}$ | $24.7 \pm 0.5$ | | $29 \pm 0.5$ | $L_{I}/M_{I} = 3.4 \pm 0.3$ | |
| | $M$ | $33.6 \pm 0.4$ | $68 \pm 5$ | $29 \pm 3$ | $M_{I}/N_{I} = 4.5 \pm 0.5$ | |
| | $N$ | $36.3 \pm 0.2$ | | $6.4 \pm 0.6$ | $N_{I}/O = 4.3 \pm 1.3$ | |
| | $O$ | $37.1 \pm 0.5$ | | $1.5 \pm 0.4$ | | |
| $225.8 \pm 0.4$ | $K$ | $142.7 \pm 0.4$ | $66 \pm 12$ | $2.5 \pm 0.3$ | $K/L = 6 \pm 3$ | 5 |
| $M1$ | $L$ | $211.3 \pm 1.7$ | | $0.4 \pm 0.2$ | | |
| $242.1 \pm 0.4$ | $K$ | $159.0 \pm 0.4$ | $70 \pm 6$ | $5.5 \pm 0.3$ | $K/L = 5.5 \pm 1.5$ | 11 |
| $M1$ | $L$ | $227.0 \pm 1.7$ | | $1.0 \pm 0.3$ | $L/M = 3 \pm 1$ | |
| | $M$ | $238.4 \pm 1.9$ | | $0.4 \pm 0.1$ | | |
| $247.3 \pm 0.5$ | $K$ | $164.2 \pm 0.5$ | $90 \pm 20$ | $1.5 \pm 0.4$ | $K/L = 3 \pm 2$ | 4 |
| (30% $M1$ + 70% $E2$)? | $L$ | $232.7 \pm 1.9$ | | $0.5 \pm 0.1$ | | |
| $279.2 \pm 0.6$ | $K$ | $196.1 \pm 0.5$ | $70 \pm 22$ | $2.0 \pm 0.4$ | $K/L \geqslant 4$ | 5 |
| $M1$ | | | | | | |
| $562 \pm 5$ | $K$ | $479 \pm 5$ | $64 \pm 9$ | $1.9 \pm 0.3$ | | 22 |
| $883 \pm 3$ | $K$ | $800 \pm 5$ | | $0.41 \pm 0.07$ | | 15 |

*Table 2.* Internal conversion lines in the decay of $Hg^{195}$ (9.5 h).

| Adopted transition energy (keV) and multipolarity | Electron energy (keV) | Conv. shell (Au) | Relative electron intensity |
|---|---|---|---|
| 61.5 ± 0.2 | 47.1 ± 0.3 | $L_I$ | 100 |
| (84 ± 9)% $M1$ + (16 ± 9)% $E2$ | 47.8 ± 0.3 | $L_{II}$ | 95 ± 5 |
| | 49.6 ± 0.2 | $L_{III}$ | 87 ± 5 |
| | 58.7 | $M$ | 61 ± 6 |
| | 60.9 | $N$ | 15 ± 2 |
| 180.2 ± 0.6[a] | 100 | $K$ | 9 ± 3 |
| $M1+E2$ | | | |

[a] According to Brunner *et al.* [7].

### 3.2. *Conversion electron spectrum of* $Hg^{195}$ *(9.5 h)*

Since the isomeric level in $Hg^{195}$ is not fed to a detectable degree in the decay of $Tl^{195}$, the growing-in mercury activity in our $Tl^{195}$ sources was supposed to offer a possibility to study the decay of $Hg^{195}$ (9.5 h) without interference from $Hg^{195m}$ (40 h). Owing to the weakness of the sources, however, only an indication of a $K$ 180 keV line [7, 8, 9] was found in addition to conversion lines of the dominant 61 keV transition [7, 8, 9]. The lines were measured on aged sources to avoid corrections for growing-in, and the results are collected in Table 2.

### 3.3. *Conversion electron spectrum of* $Hg^{195m}$ *(40 h)*

Recalling the level sequence: ground state (3/2 −), 37 keV (5/2 −) and 160 keV (13/2 +) proposed for $Hg^{195}$ from measurements on the decay of $Hg^{195m}$ [6, 7, 8, 9], the dominance of the 37 keV transition in the decay of $Tl^{195}$ (cf. Table 1) is surprising, interpreting the transition as going from the 5/2 − level to the ground state. The spin-parity ot $Tl^{195}$ is most probably 1/2 + (cf. sub-section 3.4) and the direct feeding of a 5/2 − level in $Hg^{195}$ would therefore be expected to be rather weak, since this process would be unique first forbidden. Evidence in the decays of $Tl^{199}$ and $Tl^{197}$ [1, 2] supports this surmise. On the other hand, one expects, in analogy with the level schemes of $Hg^{199}$ and $Hg^{197}$ [1, 2], a low-lying 1/2 − level in $Hg^{195}$, which ought to be comparatively strongly fed from $Tl^{195}$, the process being non-unique first forbidden. No indications of such a level were found in the decay of $Tl^{195}$ (cf. Table 1). The difficulties can be removed by supposing the ground state spin of $Hg^{195}$ to be 1/2. The 37 keV level might then be of spin-parity 3/2 − and the transition to this level from $Tl^{195}$ non-unique first forbidden. Assuming the isomeric level in $Hg^{195}$ to be 13/2 + (cf. sub-section 3.4), there is then a missing transition in the decay by internal transitions of $Hg^{195m}$ (40 h), since an $M4$–$M1$ cascade cannot bridge the spin-gap $13/2+ \rightarrow 1/2-$. Inspecting the earlier studies of the decay of $Hg^{195m}$ [6, 7, 8, 9] one finds that a possible missing transition would have to be rather low-energetic as otherwise it should certainly have been detected. (It should be remarked, however, that according to Joly *et al.* [8], who measured $Hg^{195m}$ sources and accelerated the conversion electrons with 6 kV, there should be no $Hg^{195m}$ internal conversion lines in the energy region 1–10 keV.)

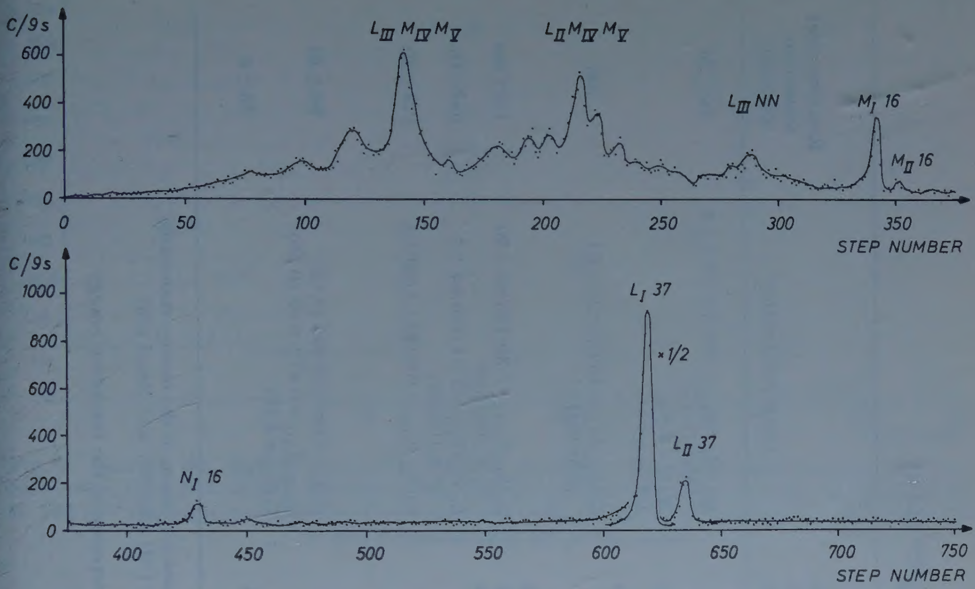

Fig. 1. Low energy part of the conversion electron spectrum of $Hg^{195m}$. The probable interpretation of some $L$-Auger lines is indicated. Counting time per point = 9 s.

Working under this assumption, we measured the $Hg^{195m}$ conversion electron spectrum from the cut-off energy of our detector (about 5 keV) and upwards. The spectrum obtained in the first run is given in Fig. 1. The peaks at step-numbers 342, 351 and 430 have not been reported in earlier studies of $Hg^{195m}$ and they are obviously not of Auger origin, since no corresponding lines were found in the $L$-Auger spectra, recorded in the studies of $Tl^{199}$ and $Tl^{197}$ [1, 2]. The relevant parts of the spectrum were

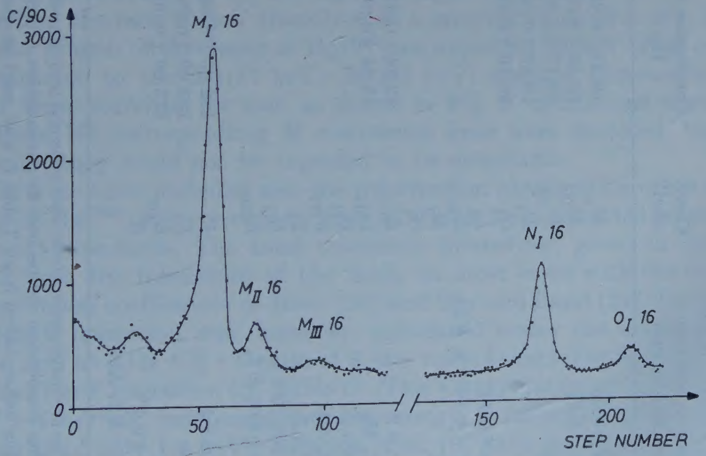

Fig. 2. Conversion lines of a 16 keV transition in the decay of $Hg^{195m}$. The break in the abscissa indicates a shift in the spectrometer current. Counting time per point = 90 s.

*Table 3.* Transitions in the decay of $Hg^{195m}$ (40 h).

| Adopted transition energy (keV), multipolarity and conversion element | Conv. shell | Calculated transition energy[a] (keV) | | Relative electron intensity | Conversion ratios[b] | Relative total transition intensity |
|---|---|---|---|---|---|---|
| | | Conversion in Hg | Conversion in Au | | | |
| $16.20 \pm 0.06$ | $M_{I}$ | $16.21 \pm 0.03$ | $16.07 \pm 0.03$ | $30 \pm 7$ | $M_{I}/M_{II}/M_{III} = 100/15 \pm 6/5 \pm 2$ | $90 \pm 20$ |
| $M1$ $(+E2)$ | $M_{II}$ | $16.20 \pm 0.03$ | $16.07 \pm 0.03$ | $4 \pm 1$ | (100/11/1) | |
| Hg | $M_{III}$ | $16.17 \pm 0.03$ | $16.06 \pm 0.03$ | $1.0 \pm 0.5$ | $M/N = 4 \pm 1$ | |
| | $N_{I}$ | $16.21 \pm 0.03$ | $16.17 \pm 0.03$ | $8 \pm 2$ | $N/O = 4 \pm 1$ | |
| | $O_{I}$ | $16.19 \pm 0.03$ | $16.20 \pm 0.03$ | $2.0 \pm 0.6$ | | |
| $37.16 \pm 0.11$[c] | $L_{I}$ | | | 100 | $L_{I}/L_{II}/L_{III} = 100/9 \pm 2/ < 1.1$ | 100 |
| $M1$ $(+ < 10^{-2}\%$ $E2)$ | $L_{II}$ | | | $9 \pm 2$ | (100/10/1) | |
| Hg | $N_{I}$ | | | $7 \pm 1$ | | |
| | $O_{I}$ | | | $1.6 \pm 0.5$ | | |
| $53.3 + 0.2$ | $L_{II}$ | $53.34 \pm 0.04$ | $52.87 \pm 0.04$ | $0.9 \pm 0.4$ | $L_{I}/L_{II}/L_{III} = < 30/100/85 \pm 30$ | $1.5 \pm 0.8$ |
| $E2$, Hg | $L_{III}$ | $53.34 \pm 0.04$ | $52.98 \pm 0.04$ | $0.8 \pm 0.4$ | (1.9/100/100) | |
| $56.7 \pm 0.2$ | $L_{II}$ | | $56.73 \pm 0.05$ | $59 \pm 5$ | $L_{I}/L_{II}/L_{III} = 3 \pm 1/100/94 \pm 5$ | $100 \pm 10$ |
| $E3$, Au | $L_{III}$ | | $56.70 \pm 0.05$ | $57 \pm 5$ | (2.3/100/90) | |
| $61.6 \pm 0.2$ | $L_{I}$ | | $61.58 \pm 0.06$ | $71 \pm 7$ | $L_{I}/L_{II}/L_{III} = 100/90 \pm 5/80 \pm 5$ | $170 \pm 20$ |
| $(84 \pm 9)\%$ $M1+$ | $L_{II}$ | | $61.64 \pm 0.06$ | $64 \pm 6$ | | |
| $(16 \pm 9)\%$ $E2$, | $L_{III}$ | | $61.59 \pm 0.06$ | $57 \pm 5$ | | |
| Au | | | | | | |
| $123.0 \pm 0.4$ | $K$ | $122.90 \pm 0.04$[d] | | $9 \pm 1$ | $K/L = 0.097 \pm 0.005$ (0.12) | $90 \pm 10$ |
| $M4$ | $L_{I}$ | $123.09 \pm 0.09$ | | $30 \pm 3$ | $L_{I+II}/L_{III} = 0.47 \pm 0.02$ (0.50) | |
| Hg | $L_{III}$ | $123.08 \pm 0.09$ | | $64 \pm 6$ | $L_{I}/L_{II} \approx 4$ (5) | |
| $560.5 \pm 0.6$[e] | $K$ | | | $1.7 \pm 0.4$ | | $58 \pm 6$ |
| $M1+E2$, Au | | | | | | |

[a] The errors given in these two columns include only the errors in line positioning and not those in the energy standards.

[b] The conversion ratios within parentheses are derived from the tables of Rose [19] and Sliv and Band [20].

[c] This value, taken from Table 1, was used as energy standard.

[d] The conversion line energies, given by Brunner *et al.* [7] indicate a similar discrepancy in the transition energy.

[e] Energy and multipolarity according to Brunner *et al.* [7].

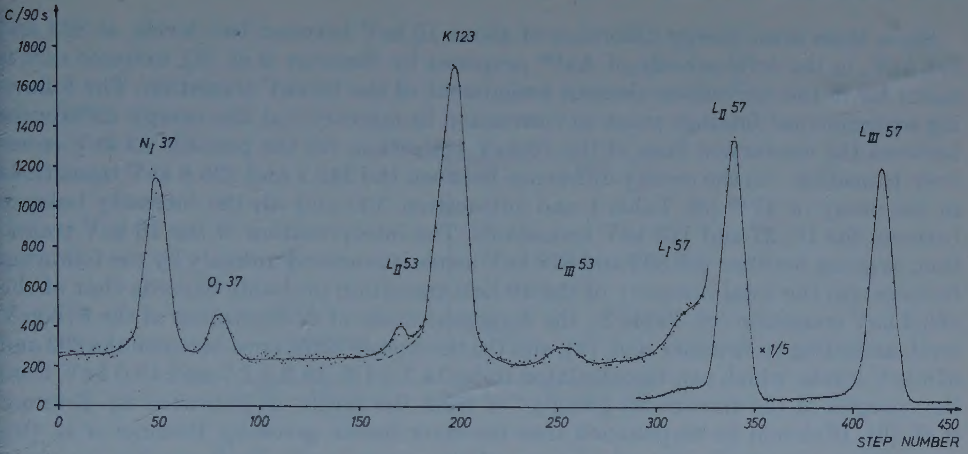

Fig. 3. Part of the $Hg^{195m}$ conversion electron spectrum showing indications of $L_{II}$ and $L_{III}$ conversion lines of a 53 keV transition. The $L_{III}$ 57 keV line was used as shape standard for the $K$ 123 keV line after correction for the natural line width (about $^1/_5$ of the experimental one) of the $K$ line. Counting time per point = 90 s.

re-measured with improved counting statistics and smaller step-lengths and, as shown in Fig. 2, the new measurement yielded some weaker conversion lines in addition to those found in the first run. As can be seen from Table 3, the energy differences between the lines strongly suggest their interpretation as $M_I$, $M_{II}$, $M_{III}$, $N_I$ and $O_I$ lines of a 16.20 keV transition, converting in mercury. Further reasons for this conversion-element assignment will be given at the end of this sub-section. The half-life of the $M_I$ line was found to be $43 \pm 5$ h from two measurements performed with an interval of 4 days. Comparison with theoretical $M$ shell conversion ratios, derived from the tables of Rose [20] suggests $M1$ multipolarity, but the low $M_I/M_{III}$ ratio may indicate an $E2$ admixture. Since Rose's calculations do not include energies below 25 keV, even an estimate of the mixing ratio appears too hazardous.

Interpreting the new 16 keV transition as a member of an $M4$–$M1$–$M1$ cascade in the internal branch of the decay of $Hg^{195m}$ one expects a 53 keV cross-over transition of $E2$ character to the $M1$(37 keV)–$M1$(16 keV) cascade. Conversion lines of this transition were searched for and, as shown in Fig. 3, indications were found of $L_{II}$ and $L_{III}$ lines. No corresponding $M$ conversion lines were detected, but, because of low intensity, they could not be expected to be detectable.

In Table 3 we have included also the information obtained on other transitions in the decay of $Hg^{195m}$, the conversion lines of which were recorded to serve as energy and intensity standards. The total transition intensities, given in the table, were calculated from the intensities of the lines, in most cases with the aid of the theoretical conversion coefficients of Rose [20] and Sliv and Band [21]. The total intensity of the 16 keV transition was, however, calculated under the assumptions of total conversion and an $L/M+N+O$ ratio of 3, this value being taken from the $L/M+N+O$ ratio of the 37 keV transition (cf. Table 1). (This extrapolation of the empirical thumb-rule $L/M+N+O \approx 3$, independent of the energy, is rather uncertain, as the $L_I$ line has an energy of only 1.4 keV.) Brunner *et al.* [9] have measured the $K$ conversion coefficient of the 560.5 keV transition to be 0.02, which was used in the intensity calculation of this transition.

Since there is an energy difference of about 15 keV between two levels, at 893 and 878 keV, in the level scheme of $Au^{195}$ proposed by Brunner *et al.* [9], extreme care is called for in the conversion-element assignment of the 16 keV transition. The following experimental findings point to conversion in mercury: (a) the energy differences between the conversion lines of the 16 keV transition, (b) the possible 53 keV cross-over transition, (c) the energy difference between the 242.1 and 225.8 keV transitions in the decay of $Tl^{195}$ (cf. Table 1 and sub-section 3.4) and (d) the intensity balance between the 16, 37 and 123 keV transitions. The interpretation of the 16 keV transition, as going between the 893 and 878 keV levels is rendered unlikely by the following findings: (a) the total intensity of the 16 keV transition probably exceeds that of the 560.5 keV transition (cf. Table 3), the dominant mode of de-excitation of the 878 keV level, according to Brunner *et al.* [9], and (b) the energy difference between the 893 and 878 keV levels, which can be calculated to be $14.7 \pm 1.6$, $15.3 \pm 1.7$ and 15.0 keV from the energies of the transitions going to or from the levels, as indicated by Brunner *et al.* [9]. It should be emphasized that the error limits, given by Brunner *et al.* [9], were added linearly in the calculations of the errors in the level spacing (no error limits were given for the transition energies from which the value 15.0 was calculated). The three values indicate an energy difference of 15.0 keV and the possibility must be rather low that this value should be 16.1 as calculated for the 16 keV transition, assuming conversion in gold. As shown in a figure given by Brunner *et al.* [9] the $K$ conversion lines of the two transitions (560.5 and 575.2 keV) yielding the difference 14.7 keV were measured in the same run, and it should be pointed out that in this case energy differences between lines are usually obtained with higher accuracy than the absolute energies of the lines.

Although each argument is rather weak, their combined evidence leads us to conclude that we have found a 16 keV transition, hitherto undetected, in the internal branch of the decay of $Hg^{195m}$. The fact that Joly *et al.* [8] did not detect the $L$ conversion lines of this transition can be explained by source absorption effects, the dominant $L_I$ line having an energy of 1.4 keV.

### 3.4. *Level scheme of* $Hg^{195}$

Neither the ground-state spins of $Tl^{195}$ and $Hg^{195}$ nor the spin of $Hg^{195m}$ have been measured, as far as is known to us.[a] However, for $Tl^{195}$ a spin of 1/2 can be inferred from a comparison of the decays of $Tl^{195m}$ (3.5 s) and $Tl^{197m}$ (0.54 s) both of which proceed via $E3$–$M1$–$M1$ cascades to the ground state [22]. The ground-state spin of $Tl^{197}$ has been measured to be 1/2 [23], the same value also being found in $Tl^{199}$, $Tl^{201}$, $Tl^{203}$ and $Tl^{205}$ [23, 24, 25, 26, 27]. The isomeric level in $Hg^{195}$ probably has a spin of 13/2 in analogy with $Hg^{197m}$, in which nuclide this value has been measured [28]. (This assumption receives some support also from the matrix elements of the $M4$ transitions in the two decays [29].) For similar reasons the ground-state spin of $Hg^{195}$ might be expected to be 1/2, the spins of $Hg^{197}$ and $Hg^{199}$ being measured to be 1/2 [28, 30, 31]. A spin of 3/2 has, however, been measured in $Hg^{201}$ [30], and $Hg^{193}$ has been proposed to have this spin also [7]. The nuclear shell model predicts negative parity for the $Hg^{195}$ ground state and positive parity for $Tl^{195}$ and $Hg^{195m}$.

Assuming, in accordance with the last paragraph, a spin-parity of $13/2+$ for $Hg^{195m}$, one concludes that the 123 keV $M4$ transition (cf. Table 3) feeds a $5/2-$ level, this

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[a] *Note added in proof:* The ground-state spin of $Tl^{195}$ has recently been measured to be 1/2 by Olsmats and Axensten, University of Uppsala (private communication).

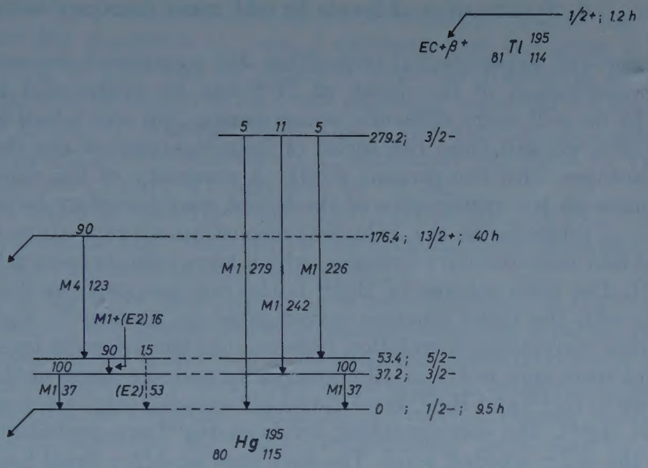

Fig. 4. Proposed level scheme of $Hg^{195}$. All energies are in keV and the figures at the tails of the transition arrows indicate the relative total transition intensities, as calculated from the conversion line intensities. The differences in the calculated intensities of the 16, 37 and 123 keV transitions are not significant.

transition undoubtedly going directly from the isomeric level. The total intensity values given in Table 3 show that the 5/2 − level is dominantly depopulated through an $M1$(37 keV)–$M1$(16 keV) cascade. The ground-state spin of $Hg^{195}$ is thus 1/2. The order of emission of the 16 and 37 keV transitions cannot be ascertained from the decay of $Hg^{195m}$ alone, but the ambiguity can be removed by comparison with the decay of $Tl^{195}$. The upper intensity limit of an $M_I$ 16 keV conversion line in this decay is 2.5 % of the $L_I$ 37 keV conversion line and thus considerably lower than the $M_I$ $16/L_I$ 37 intensity ratio (0.30) found in the decay of $Hg^{195m}$ (cf. Table 3), which clearly shows that the 37 keV transition goes to the ground state. This is expected also from the dominance of the 37 keV transition in the decay of $Tl^{195}$ (cf. sub-section 3.1).

From the discussion given above one concludes the following internal decay scheme of $Hg^{195m}$: 176 keV (13/2 +), 53 keV (5/2 −), 37 keV (3/2 −) and ground state (1/2 −) (cf. Fig. 4).

This level sequence gains support also from other findings in the decay of $Tl^{195}$. The energy difference between the 279, 242 and 226 keV transitions (cf. Table 1) strongly indicates a level at 279 keV, de-exciting to the 53 and 37 keV levels and to the ground state. All three transitions are at least partially of $M1$ character and the spin-parity of the 279 keV level is thus 3/2 −. The weakness of the 226 keV transition explains why no conversion lines of the 16 keV transition were found in the decay of $Tl^{195}$. The remaining three $\gamma$-transitions detected in the decay of $Tl^{195}$ (247, 562 and 885 keV) could not be placed in the level scheme (cf. Fig. 4).

Preliminary measurements [32] of the positron spectrum of $Tl^{195}$ indicate a complex spectrum with an end-point energy of about 1.8 MeV. Since strong positron branches to low-lying levels in $Hg^{195}$ can be expected, a total decay energy of about 2.8 MeV can be inferred from the measurements. The low intensity of all lines in the conversion electron spectrum of $Tl^{195}$, except those of the 37 keV transition, is readily explained by the high $Q$-value, since the total decay intensity must be surmised to be shared among many levels, the decay of which should proceed via several competing $\gamma$-transitions.

## 4. Systematics of levels in odd mass mercury isotopes

Since improved experimental techniques are considered necessary before a more detailed investigation of the decay of $\mathrm{Tl}^{195}$ can be made, and a study of $\mathrm{Tl}^{193}$ is expected to be still more difficult, remembering the short half-life of this nuclide (23 min [12]), we will close the series of investigations of the decays of odd mass thallium isotopes with the present study. A summary of the experimental findings, with emphasis on the systematics of the levels, may therefore be appropriate.

For ease of reference in the following discussion we reproduce in Fig. 5 the level schemes of odd mass mercury isotopes, which have been proposed by various authors [1, 2, 3, 7]. The level scheme of $\mathrm{Hg}^{195}$ is the one proposed in the present work.

Starting with the three schemes investigated by us ($\mathrm{Hg}^{195}$, $\mathrm{Hg}^{197}$ and $\mathrm{Hg}^{199}$) one finds a rather convincing correlation between the three lowest levels in each nucleus. The ground-state spin is 1/2 in all three nuclei and the spins of the first and second exited levels in $\mathrm{Hg}^{199}$ and $\mathrm{Hg}^{197}$ are 5/2 and 3/2, respectively, whereas the reverse order is found in $\mathrm{Hg}^{195}$. The corresponding levels in $\mathrm{Hg}^{193}$ are probably the $3/2-$ ground state and the $5/2-$ excited level. The fact that no $1/2-$ level has been observed in this nucleus can be explained by a crossing of the $3/2-$ and $1/2-$ levels, since the latter would then be only weakly fed in the decay of $\mathrm{Hg}^{193m}$. No level scheme of $\mathrm{Hg}^{193}$, excited in the decay of $\mathrm{Tl}^{193}$, has yet been proposed.

According to the naive single particle model, the three low-lying levels would be interpreted as $p_{1/2}$, $p_{3/2}$ and $f_{5/2}$ states. The $M1$ transition between the $f_{5/2}$ and the $p_{3/2}$ levels should in this picture be $l$-forbidden. The experimental evidence in $\mathrm{Hg}^{199}$ is that this transition (50 keV) may have an $E2$ admixture of about 0.1 % [1] but that it does not appear to be hindred as compared to the 208 keV transition ($p_{3/2} \to p_{1/2}$), which, on the other hand, has an 11 % $E2$ component [33]. In $\mathrm{Hg}^{197}$ the $f_{5/2} \to p_{3/2}$ transition is rather low-energetic (18 keV) and no reliable estimate of possible $E2$ admixture can be made. The $M_{\mathrm{I}}/M_{\mathrm{III}}$ ratio (10 [2]) appears, however, to be lower than the theoretical value for a pure $M1$ transition, which may indicate an $E2$ component. The $E2$ admixture to the $p_{3/2} \to p_{1/2}$ transition in this nucleus is less than

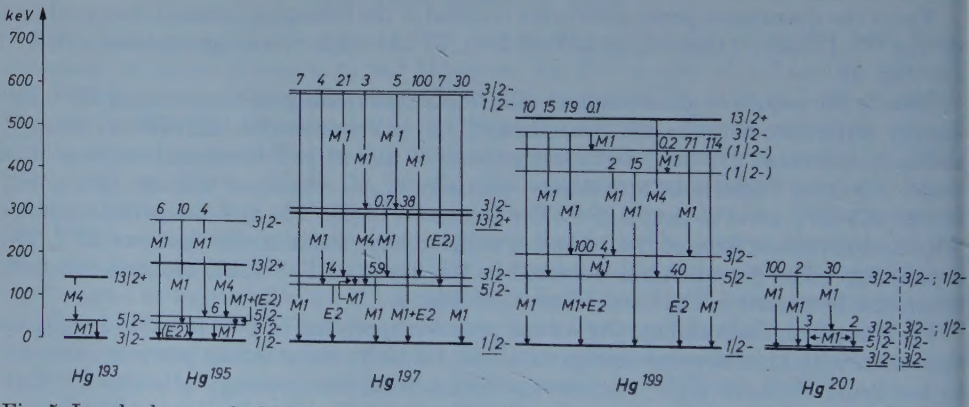

Fig. 5. Level schemes of odd mass mercury nuclei. The figures at the tails of the transition arrows indicate relative *γ-intensities*, as found in the decays of the corresponding thallium isotopes. The level schemes are taken from various investigators [1, 2, 3, 7], that of $\mathrm{Hg}^{195}$ being taken from the present work. Measured spin values are underlined. The two sets of spin assignments in $\mathrm{Hg}^{201}$ are proposed by Herrlander *et al.* [3].

2 %. The intensity of the possible 53 keV $E2$ transition ($f_{5/2} \rightarrow p_{1/2}$) in $Hg^{195}$ as compared to the 16 keV $M1$ transition ($f_{5/2} \rightarrow p_{3/2}$) indicates that the latter is hindered. (An $E2/M1$ branching of $1/10^4$ can be expected from the Weisskopf estimate, according to the diagrams of half-lives for $\gamma$-ray emission, corrected for internal conversion, which are given by Wapstra *et al.* [34].) The high $M_I/M_{III}$ ratio of the 16 keV transition ($f_{5/2} \rightarrow p_{3/2}$) may indicate an $E2$ admixture (cf. Table 3). The 37 keV transition ($p_{3/2} \rightarrow p_{1/2}$) is very pure $M1$ (less than $10^{-2}$ % $E2$).

The third excited levels in both $Hg^{195}$ and $Hg^{197}$ have spin-parity 13/2+ and corresponding levels are found in $Hg^{193}$ and $Hg^{199}$. The systematics of these levels ($i_{13/2}$ in single particle notation) has been studied earlier [29].

The fourth excited levels (of those which have been detected) in $Hg^{195}$ and $Hg^{197}$ have spin-parity 3/2−. The ground-state transition from the level in $Hg^{197}$ is of mixed $M1+E2$ character (50 % $M1$ + 50 % $E2$) and the $E2$ admixture to the corresponding transition in $Hg^{195}$ may be as high as 60 % (no $L$ conversion lines of this transition were detected, however, cf. Table 1). No correspondence to these levels has yet been found in $Hg^{193}$. In $Hg^{199}$ the corresponding level may be found at 403 keV (earlier proposed to be 1/2−, but 3/2− is not excluded) or at 492 keV. For the remaining levels found in $Hg^{197}$ and $Hg^{199}$ it is perhaps too dangerous to draw any systematic analogies, but it might be of some significance that one finds rather close-lying levels of spin-parity 1/2− and 3/2− in both nuclei (assuming the 403 keV level in $Hg^{199}$ to be 3/2−).

Interpreting the low-lying levels in $Hg^{197}$ and $Hg^{199}$ as odd neutron states ($p_{1/2}$, $p_{3/2}$ and $f_{5/2}$) it is tempting to describe the higher 1/2− and 3/2− states as due to a coupling of the odd neutron to a nuclear surface quadrupole oscillation. The first exited 2+ levels in the neighbouring even-even nuclei $Hg^{196}$, $Hg^{198}$ and $Hg^{200}$ have energies of 426, 412 and 368 keV, respectively. This type of coupling, which was first suggested for $Hg^{199}$ by Bergström *et al.* [35], has received increasing theoretical interest in recent years (cf. Glendenning [36] and Bayman and Silverberg [37] and references given by them). In this coupling scheme a 1/2− level can arise either from a coupling of a 3/2− or a 5/2− neutron. Only one 1/2− level is detected in $Hg^{197}$ and $Hg^{199}$ (assuming the 403 keV level to be 3/2−). Since the $f_{5/2}$ levels in these nuclei are only weakly fed directly from $Tl^{197}$ and $Tl^{199}$ it is natural to guess that the detected level is due to a coupling of the $p_{3/2}$ neutron. Two 3/2− levels are detected and for similar reasons they probably arise from a coupling of the $p_{1/2}$ and $p_{3/2}$ neutrons. From the systematics of the levels one is lead to assume that the 403 and 309 keV (3/2−) levels in $Hg^{199}$ and $Hg^{197}$, respectively, arise from a coupling of a $p_{1/2}$ neutron and that the 455 (1/2−) and 492 (3/2−) keV levels in $Hg^{199}$ and the 578 (1/2−) and 585 (3/2−) keV levels in $Hg^{197}$ are due to a coupling of a $p_{3/2}$ neutron. It is noteworthy that stronger preference between the low-lying levels is not observed in the de-excitation of the higher levels in $Hg^{199}$. Possible $E2$ admixture to the transitions between the higher and lower groups could not be studied for energetic reasons. In $Hg^{197}$ it appears that the 578 and 585 keV levels prefer to de-excite to the 152 keV level. The high energies of the favoured transitions prevented a study of possible $E2$ admixture. The ground-state transition from the 309 keV level in $Hg^{197}$ has a rather large $E2$ component (50 %) and this transition also appears to be favoured over the competing ones. No similar preference is observed in the decay of the 279 keV (3/2−) level in $Hg^{195}$.

As may be apparent from the discussion above, we have found very little correspondence between the levels in $Hg^{201}$ and those in the lower odd mass isotopes. Even

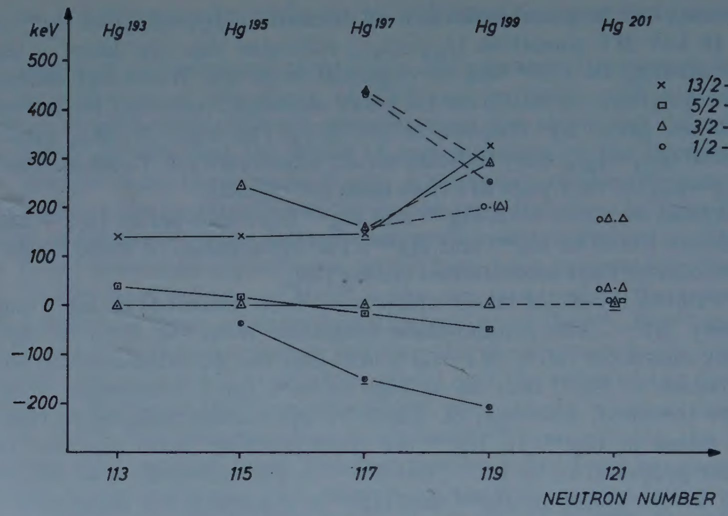

Fig. 6. Level spacings in odd mass mercury isotopes. The association of levels is according to the discussion given in the text. Underlined spin symbols indicate that the spin has been measured. The two sets of spin assignments in $Hg^{201}$, given by Herrlander *et al.* [3], are indicated.

with rather drastic changes in the assumed relationships between the levels in the lower mass isotopes, it seems rather difficult to acocunt for all the low-lying levels in $Hg^{201}$. The ambiguity in the spins of the $Hg^{201}$ levels does not make this task easier.

In Fig. 6 we illustrate the energy differences between the levels as a function of neutron number, associating the levels according to the discussion given earlier. The lowest-lying 3/2 − levels were chosen as reference, since low-lying levels of this spin-parity are found in all five nuclei. It is uncertain, however, if the 3/2 − ground state in $Hg^{201}$ should be associated with the 3/2 − levels in the other nuclei. A rather regular behaviour of the level spacings when neutron pairs are added or subtracted is evident from the figure, neglecting $Hg^{201}$.

The calculations with a pairing plus a long range force of level energies in single closed shell nuclei by Kisslinger and Sorensen [38] have rather successfully accounted for the level sequences found in odd mass lead nuclei, and may indicate a promising approach to a theoretical understanding of the levels in the odd mass mercury isotopes, too. However, the pair of proton holes in these nuclei apparently changes the level energies considerably, as a comparison of the mercury and lead levels reveals, and the coupling between the proton and neutron holes should therefore be included in the calculations.

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